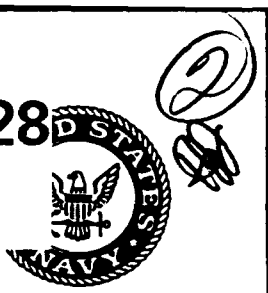

Naval Medical Research Institute

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# METABOLIZABLE ENERGY INTAKES AND NITROGEN BALANCE DURING SATURATION DIVING

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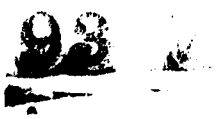



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## TECHNICAL REVIEW AND APPROVAL

## NMRI 93-20

The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

ROBERT G. WALTER
CAPT, DC, USN
Commanding Officer
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Body compositions and energy and nitrogen balances were measured during a study to define nutrient requirements in saturation diving. Divers were studied at the surface and during saturation dives at pressures of 0.56 and 3.17 MPa. A controlled diet provided 15.06 MJ and about 100 gm of protein daily with 30% of energy from fat. In balance studies, a duplicate of each meal and all urine and feces were collected. The samples were composited, homogenized, lyophilized, and analyzed for energy and nitrogen content. Body weights, underwater weights and deuterium spaces were measured periodically. Means(SD) were:

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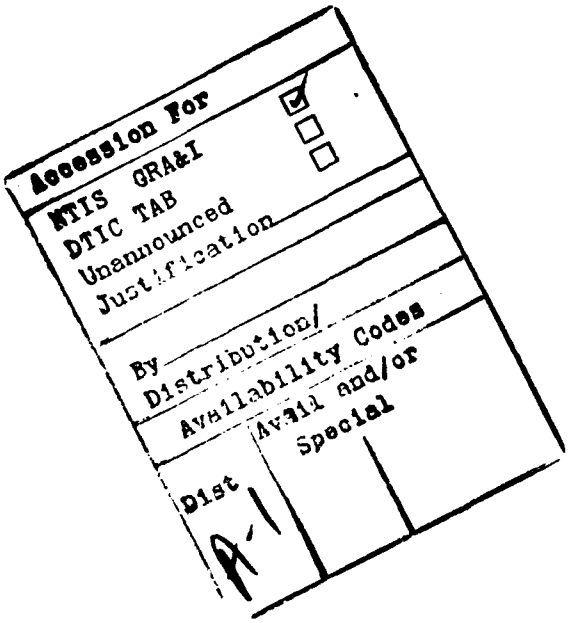
| PRESSURE (MPa) | NUMBER SUBJECTS | INTAKE (MJ/DAY) | WEIGHT CHANGE (KG) | N BALANCE (GM/DAY) | MET ENERGY (PERCENT) |
|---|---|---|---|---|---|
| SURFACE | 11 | 16.28(.82) | NA | +5.0(4.3) | 90.7(4.1) |
| 0.56 | 7 | 16.39(.61) | +0.34(1.28) | +3.5(7.1) | 91.7(1.9) |
| 3.17 | 13 | 11.99(.92) | -1.92(1.68) | -0.9(4.6) | 88.7(3.4) |

The results indicate that energy losses due to digestion, absorption and incomplete oxidation are similar in normobaric and hyperbaric conditions. Divers at the surface and at 0.56 MPa consumed enough nutrients to match energy expenditure. At 3.17 MPa, intake was less because divers did not consume all that was provided; the amount consumed was inadequate to meet energy requirements.





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## BACKGROUND

Webb has summarized the results of earlier studies to evaluate metabolism in divers living under saturation diving conditions (1). In several of those studies, divers lost weight during the dives in spite of energy intakes that were considered adequate to high. In one of the more detailed studies of energy metabolism (2), Webb found that divers at 1.88 MPa (18.6 atmospheres absolute) lost weight even though they consumed more energy (about 3500 Kcal or 14.64 MJ per day) than they expended (2431 Kcal or 10.17 MJ per day according to indirect calorimetry measurements). The investigators could not explain the reason for the apparent additional, unmeasured energy expenditure. Digestibility and metabolism measurements indicated that nutrients were used with the same efficiency at depth as at the surface. Measurements of deuterium space showed that the weight loss was not due to loss of body water by excess dehydration or diuresis. One possible explanation for the discrepancy between energy expenditure and energy consumption could be that the indirect calorimetry measurements underestimated true energy expenditure. Early investigators also found changes in water metabolism during saturation diving with increased urine output and a decrease in insensible water loss (1).

Our research was designed to evaluate changes in energy, protein, and water metabolism and to better define the nutritional requirements for saturation diving. Compared to earlier investigators, we had the opportunity to study larger numbers of subjects and to use newer methods to study metabolism with stable isotopes. We used deuterium and oxygen-18 to evaluate energy and water metabolism and nitrogen-15 to evaluate protein metabolism. Energy and nitrogen balances and body composition

changes were measured to complement the studies with stable isotopes. This report describes the results of the measurements of energy and nitrogen balance and body composition changes. Results of all studies have been reported in abstract form (3-6), and other reports (7,8) discuss other aspects of the research.

## METHODS

### Hyperbaric Conditions

Studies were completed between February 1989 and May 1990 in the Man-Rated Chamber Complex (MRCC) at the Naval Medical Research Institute, Bethesda, MD (NMRI). The chamber atmosphere was .0455 MPa oxygen with the balance helium plus varying amounts of nitrogen up to but never exceeding .101 MPa nitrogen. Humidity and temperature were controlled to provide maximum comfort to the divers and to prevent thermal stress. The total times for compression, bottom time, and decompression were 11 days for dives to 0.56 MPa and 28 days for dives to 3.17 MPa. All balance studies under pressure were completed during the period after the divers had been at their maximum pressure for at least 24 hours and before decompression had started.

Metabolic studies were conducted with divers at SURFACE, 0.56 MPa, and 3.17 MPa. There were six saturation dives (three at 0.56 MPa and three at 3.17 MPa) with three to five subjects per dive. During the two weeks before each dive, the subjects did not live in the MRCC, but they completed the same exercises they would subsequently complete while in the chamber. The SURFACE studies were completed with the divers

out of the MRCC during the Monday through Friday period of the week before each 0.56 MPa dive started.

Subjects

Subjects were U.S. Navy divers stationed at NMRI who voluntarily consented to participate. Research plans were approved by the NMRI's Committee for the Protection of Human Subjects and by the United States Department of Agriculture's Human Studies Committee.

Menus

Previous studies had indicated that energy requirements would be about 15.06 MJ per day. Fifteen daily menus were designed to provide 15.06 MJ and about 100 gm protein daily with 30% of energy from fat. One menu is completely described in Table 1. The other menus are described in reference (9). For each dive, the dive team chose seven of the menus that were most acceptable to all divers, and those menus were used for the duration of the dive. All food was prepared by U.S. Navy Mess Specialists.

Sample Collection

For each balance study, individual meals were prepared by weighing each component to the nearest gram as required by the menu. One additional meal was prepared and added to a composite for later analysis. Any food that was not consumed (refused) was collected after the meal and added to a composite for each subject. All stool (identified by use of stool markers given at the beginning and end of each balance period) was collected and added to a composite for each diver. All urine was collected and aliquots

were added to a composite for each diver. Composites were homogenized and lyophilized for analysis. Nitrogen and energy content was measured for each composite.

Body Weight

Body weight was measured before and after each dive on an electronic scale calibrated and accurate to the nearest gram. Body weight in the chamber was measured daily by use of a spring scale accurate to the nearest pound. Weights measured in the chamber were converted to metric values mathematically.

Additional measurements were used to evaluate changes in body composition. For studies at 0.56 MPa, total body water was measured as deuterium space just before the dive started and again at the end of the dive. For studies at 3.17 MPa, lean body mass was calculated from underwater weights for each diver just before the dive started and again at the end of the dive. Deuterium space was measured after the divers had been at 3.17 MPa for 24 hours and also just before decompression started.

Data Analysis

Data were analyzed by one-way Analysis of Variance. A "P" value of less than 0.05 was considered necessary to define deviations as statistically different.

## RESULTS

Subjects

Data for all subjects are presented in Tables 2-9 and summarized in Table 10. Three teams (11 divers) completed the studies at SURFACE. Because one dive had to be ended early after an injury, only two teams (7 divers) completed the studies at

0.56 MPa. All divers who completed the 0.56 MPa studies also completed studies at SURFACE. Three teams (13 divers) completed the studies at 3.17 MPa, but only four of those subjects also completed the studies at SURFACE and 0.56 MPa. In Tables 2-9, each diver has the same identifier for all studies in which he participated, i.e., the same person was "DVR-01" in studies at SURFACE, 0.56 MPa, and 3.17 MPa.

Food Intake

In the original design of the menus, there was no provision for evening snacks. Before diving actually started, several teams requested that snacks should be provided. This request was honored, the snack was added to the daily menu and equivalent amounts were added to the composite for analysis. For that reason, Tables 3 and 4 indicate that the divers at SURFACE and 0.56 MPa received more than the expected (calculated values of menus) 15.06 MJ per day. The menus were reconfigured so that the food provided for an evening snack was part of the 15.06-MJ allotment during studies at 3.17 MPa.

Based upon analysis of food composites, all divers received at least 14.43 MJ per day (Tables 2-4), but at 3.17 MPa large amounts were refused by several divers. Average intakes (Table 10) were 16.28, 16.39 and 11.99 MJ per day at SURFACE, 0.56 MPa, and 3.17 MPa, respectively. Similarly, the nitrogen intakes (Table 10) of 21.3, 20.0, and 16.4 grams per day at SURFACE, 0.56 MPa, and 3.17 MPa, respectively, reflect the relatively high food refusals at 3.17 MPa.

Body Weight

Average weight change (Tables 9 and 10) from beginning to end of the 0.56 MPa studies was +0.34 kg. During that period two divers lost weight, the others gained weight. Total body water increased in three divers and decreased in four with a mean change of -0.24 kg.

For the 14-day period at 3.17 MPa (Tables 8 and 10), ten divers lost weight, two gained, and one had no change; the mean changes were a loss of 1.92 kg of weight and a loss of 1.63 kg of total water. For the entire 28 days of the dive at 3.17 MPa, the mean weight change was a loss of 2.61 kg; all divers lost weight for that period. Average lean body mass was 1.90 kg lower at the end of the dive than at the beginning.

Nitrogen Balance

Nitrogen balance (Table 10) was slightly positive at SURFACE (5.0 grams per day) and at 0.56 MPa (3.5 grams per day). Nitrogen balance at 3.17 MPa was negative (-0.90 grams per day).

Energy Utilization

Energy digestibilities {[(energy consumed - energy in stool) / energy consumed] X 100} were 93.5, 94.1 and 93.1 per cent at SURFACE, 0.56 MPa, and 3.17 MPa, respectively (Table 10). Metabolizable energy values {[(energy consumed - energy in stool - energy in urine) / energy consumed] X 100} were 90.7, 91.7, and 88.7 per cent at SURFACE, 0.56 MPa and 3.17 MPa, respectively (Table 10).

## DISCUSSION

Energy expenditure was measured for these subjects by using doubly labeled water (4,8). The average energy expenditures were 13.0 ± 0.4, 14.7 ± 0.5, and 14.8 ± 0.5 MJ per day at SURFACE, 0.56 MPa, and 3.17 MPa, respectively. Divers at SURFACE and 0.56 MPa consumed adequate calories to meet those energy needs and, in most cases to gain weight. The positive nitrogen balances under those conditions support those conclusions. The short duration of each balance study and dive period would not allow much change in body weight during those periods. However, the relatively small gain measured at 0.56 MPa is further support that the divers received more than adequate nutrients during the study and that energy expenditure was accurately measured by the use of doubly labeled water.

Earlier research (10) has indicated that fluid metabolism changes under hyperbaric conditions and that there might be some diuresis during compression. In addition, measurement of body weight is affected by the buoyancy of helium. Therefore, body composition was studied for two different periods of the studies at 3.17 MPa: changes during the entire time in the MRCC and changes while under pressure of 3.17 MPa only. Because we expected significant changes in body water during compression, deuterium space was first measured after the divers had been at depth for at least 24 hours. Similarly, the balance studies were completed and changes in body weight at depth were calculated only after this acclimation period. The second measurement of deuterium space was obtained on the last day divers were at 3.17 MPa.

During the studies at 3.17 MPa, average body weight decreased by .58 kg during the three days of compression. This probably represents a loss of body water rather than other tissue. During the two weeks at 3.17 MPa, 10 of 13 subjects lost more weight. The mean change was a loss of 1.92 kg, but seven divers lost more than 2.5 kg. Divers who lost the most weight also had the lowest energy intake (Figure 1). In fact, three of the four divers who consumed more than 12.55 MJ per day had minimal or no weight change. This is further evidence that actual energy expenditure was the same as measured by the use of doubly labeled water. Deuterium space decreased from 48.36 to 46.73 kg, a loss of 1.63 kg. Results of the body composition studies with underwater weights and with deuterium indicate that both fat and lean body mass decreased during the 3.17 MPa dive.

If the subjects had eaten all the food that was provided at 3.17 MPa, they would have matched their energy expenditure and should have been able to maintain weight. There is no good explanation for why they did not seem to be hungry enough to eat all the food that was provided. There were no reports of unusual changes in taste, odor or other food characteristics. In general, health was excellent during the dives. Confinement alone should not have caused the poor intake, because intake was excellent during the studies at 0.56 MPa where confinement lasted almost as long as it had when the balance studies were completed at 3.17 MPa.

Differences in metabolizable energy and digestible energy values were not statistically significant. The results indicate that energy losses due to digestion, absorption, and incomplete oxidation of nutrients are similar in normobaric and in the

hyperbaric conditions of this study. Planning menus for use in hyperbaric conditions can therefore be developed by the use of food composition values available in standard references.

## CONCLUSIONS

1) The estimates of energy expenditure by use of doubly labeled water are correct for the conditions of this study.

2) Energy expenditure is increased under hyperbaric conditions compared to performing similar activities under normobaric conditions.

3) For saturation dives with exposure to heavier work and thermal stress, higher nutrient intake will be required than indicated by our measurements. Divers in our studies were primarily dry with relatively low exercise rates, and with temperature and humidity controlled to minimize stress.

4) Metabolism values obtained under normobaric conditions can be used to plan diets for use during saturation diving. Nutrients will be utilized the same under both conditions.

5) Different diets and strategies may be needed to increase caloric intake by saturation divers working at great depth. The subjects at 3.17 MPa did not complain of hunger and frequently returned uneaten food. This happened in spite of the fact that their energy expenditure was greater than their intake and they experienced significant weight loss while at the greatest depth.

## REFERENCES


1. Webb, P. "Current concepts of metabolism and thermophysiology." In: Bachrach, A.J. and Matzen, M.M., eds. Proceedings of the Seventh Symposium on Underwater Physiology. Undersea Medical Society, Bethesda, MD, pp. 493-502, 1981.
2. Webb, P., et al. "Hana Kai II: a 17-day dry saturation dive at 18.6 ATA. II. Energy balance." Undersea Biomedical Research, Vol. 4, pp. 21-246, 1977.
3. Thorp, J.W., Seale, J.L., Conway, J.M., Rumpler, W.V., Haberman, K.J., and Doubt, T.J. "Weight and body composition during 31 atmosphere (ATA) saturation dive." Undersea Biomedical Research, Vol. 18, p. 94 (abstr), 1991.
4. Seale, J.L., Rumpler, W.V., Conway, J.M., Thorp, J.W., and Haberman, K.J. "Energy expenditure and water and urine production at the surface and during saturation dives at 5.5 and 31 atmospheres (ATA)." Undersea Biomedical Research, Vol. 18, p. 94 (abstr), 1991.
5. Rumpler W.V., Thorp J.W., Seale, J.L., Conway, J.M., and Haberman, K.J. "Metabolizable energy intake and nitrogen balance during saturation dives." Undersea Biomedical Research, Vol. 18, p. 95 (abstr), 1991.
6. Conway, J.M., Thorp, J.W., Stein, T.P., Seale, J.L., and Rumpler, W.V. "Decreased protein synthesis during saturation diving." Undersea Biomedical Research, Vol. 18, p. 95 (abstr), 1991.

7. Conway, J.M., Thorp, J.W., Stein, T.P., Seale, J.L., Rumpler, W.V. "Decreased protein synthesis during dry saturation diving." Undersea Biomedical Research (submitted), 1992.

8. Seale, J.L., Thorp, J.W., Conway, J.M., Rumpler, W.V., and Haberman, K.J. "Energy expenditure and fluid production in hyperbaric He-$O_2$ environments using $^{2}H_2$ $^{18}O$." Undersea Biomedical Research (submitted), 1992.

9. Thorp, J.W. and Doubt, T.J. Recommended dietary menus for use in operational and research saturation diving. NMRI Technical Report No. 91-21. Naval Medical Research Institute, Bethesda, MD, 1991;

10. Nakayama, H., et al. "Energy and body fluid balance during a 14-day dry saturation dive at 31 ATA (Seadragon IV)." In: Bachrach, A.J. and Matzen, M.M., eds. Proceedings of the Seventh Symposium on Underwater Physiology. Undersea Medical Society, Bethesda, MD, pp. 541-554, 1981.

## TABLE 1

One of fifteen daily menus used for evaluating nutrition status of divers during saturation diving. Each diver's meal was individually prepared according to the menu. An additional composite meal was prepared and saved for analysis. Calculated analysis for this menu: Total Energy = 14.92 MJ; Protein = 131 gm and 15% of energy; Fat = 107 gm and 27% of energy; Carbohydrate = 521.4 gm and 58% of energy.

| | |
|---|---|
| BREAKFAST | |
| MILK-2% FAT | 336.0 GMS |
| APPLE JUICE | 248.0 GMS |
| BACON-FRIED | 31.5 GMS |
| CEREAL-CHEERIOS | 34.1 GMS |
| MUFFIN-ENGLISH | 56.0 GMS |
| JAMS/PRESERVES | 40.0 GMS |
| MARGARINE-CORN | 4.7 GMS |
| SUGAR | 24.0 GMS |
| LUNCH | |
| VEGETABLE SOUP-CANNED | 480.0 GMS |
| SANDWICH | |
| TUNA-WHITE-CANNED IN WATER | 85.0 GMS |
| SALAD DRESSING-LOW CAL | 48.0 GMS |
| WHOLE WHEAT BREAD | 84.0 GMS |
| ICEBERG LETTUCE | 28.3 GMS |
| CORN CHIPS | 56.7 GMS |
| APPLE JUICE | 496.0 GMS |
| DINNER | |
| TURKEY BREAST-NO SKIN-ROAST | 136.1 GMS |
| GRAVY-CHICKEN | 119.0 GMS |
| NOODLES-EGG | 160.0 GMS |
| ZUCCHINI SQUASH-FROZEN-BOIL | 223.0 GMS |
| CRANBERRY SAUCE | 277.0 GMS |
| TEA-INSTANT | 474.0 GMS |
| EVENING SNACK | |
| ICE CREAM | 222.0 GMS |

## TABLE 2

Energy data for saturation dive at 3.17 MPa.

| Subject | TOTALS FOR STUDY PERIOD | | | | | | | Daily Intake (MJ) | Digested (Percent) | Metabolized (Percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Study Days | Provided (MJ) | Refused (MJ) | Consumed (MJ) | Stool (MJ) | Urine (MJ) | Metabolized (MJ) | | | |
| DVR-01 | 7.0 | 101.27 | 20.46 | 80.82 | 8.21 | 3.28 | 69.33 | 11.55 | 89.8 | 85.8 |
| DVR-02 | 7.0 | 101.27 | 17.91 | 83.36 | 4.93 | 3.10 | 75.32 | 11.91 | 94.1 | 90.4 |
| DVR-03 | 7.0 | 102.40 | 20.49 | 81.91 | 4.14 | 3.54 | 74.23 | 11.70 | 94.9 | 90.6 |
| DVR-06 | 7.0 | 108.40 | 18.43 | 89.97 | 5.80 | 6.64 | 77.52 | 12.85 | 93.5 | 86.2 |
| DVR-09 | 7.0 | 102.40 | 24.85 | 77.55 | 5.15 | 3.06 | 69.33 | 11.08 | 93.4 | 89.4 |
| DVR-10 | 7.0 | 101.27 | 29.04 | 72.23 | 4.16 | 3.74 | 64.34 | 10.32 | 94.2 | 89.1 |
| DVR-11 | 7.0 | 102.40 | 16.12 | 86.27 | 5.29 | 1.77 | 79.21 | 12.32 | 93.9 | 91.8 |
| DVR-12 | 7.0 | 101.27 | 27.67 | 73.60 | 3.55 | 2.75 | 67.30 | 10.51 | 95.2 | 91.4 |
| DVR-13 | 7.0 | 108.40 | 17.59 | 90.82 | 4.09 | 3.50 | 83.23 | 12.97 | 95.5 | 91.6 |
| DVR-14 | 7.0 | 102.40 | 11.68 | 90.71 | 5.33 | 4.13 | 81.25 | 12.96 | 94.1 | 89.6 |
| DVR-15 | 7.0 | 108.40 | 21.26 | 87.14 | 4.17 | 5.21 | 77.76 | 12.45 | 95.2 | 89.2 |
| DVR-17 | 7.0 | 108.40 | 16.89 | 91.51 | 14.86 | 4.29 | 72.36 | 13.07 | 83.8 | 79.1 |
| DVR-19 | 7.0 | 108.40 | 22.23 | 86.17 | 5.92 | 3.53 | 76.72 | 12.31 | 93.1 | 89.0 |

## TABLE 3

Energy data for saturation dive at 0.56 MPa.

| Subject | TOTALS FOR STUDY PERIOD | | | | | | | Daily Intake (MJ) | Digested (Percent)) | Metabolized (PERCENT) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Study Days | Provided (MJ) | Refused (MJ) | Consumed (MJ) | Stool (MJ) | Urine (MJ) | Metabolized (MJ) | | | |
| DVR-01 | 6.0 | 101.36 | 0.00 | 101.36 | 5.38 | 4.68 | 91.30 | 16.89 | 94.7 | 90.1 |
| DVR-04 | 7.0 | 101.36 | 1.08 | 100.28 | 6.14 | 4.76 | 89.38 | 16.71 | 93.9 | 89.1 |
| DVR-05 | 7.0 | 119.77 | 1.36 | 118.41 | 6.87 | 0.12 | 111.42 | 16.92 | 94.2 | 94.1 |
| DVR-09 | 7.0 | 119.77 | 9.04 | 110.74 | 6.43 | 0.72 | 103.58 | 15.82 | 94.2 | 93.5 |
| DVR-11 | 7.0 | 119.77 | 5.94 | 113.83 | 7.16 | 2.66 | 104.01 | 16.26 | 93.7 | 91.4 |
| DVR-14 | 7.0 | 119.77 | 12.53 | 107.24 | 6.67 | 0.80 | 99.77 | 15.32 | 93.8 | 93.0 |
| DVR-16 | 6.0 | 101.36 | 0.44 | 100.92 | 5.47 | 4.12 | 91.33 | 16.82 | 94.6 | 90.5 |

## TABLE 4

Energy data for studies at SURFACE.

| Subject | Study Days | TOTALS FOR STUDY PERIOD Provided (MJ) | Refused (MJ) | Consumed (MJ) | Stool (MJ) | Urine (MJ) | Metabolized (MJ) | Daily Intake (MJ) | Digested (Percent) | Metabolized (Percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| DVR-01 | 4.7 | 71.66 | 0.00 | 71.66 | 2.95 | 2.96 | 65.75 | 15.35 | 95.9 | 91.8 |
| DVR-04 | 4.7 | 71.66 | 0.00 | 71.66 | 3.52 | 1.95 | 66.19 | 15.35 | 95.1 | 92.4 |
| DVR-05 | 5.0 | 80.16 | 0.00 | 80.16 | 4.50 | 2.77 | 72.90 | 16.03 | 94.4 | 90.9 |
| DVR-07 | 4.7 | 79.91 | 0.65 | 79.26 | 3.54 | 1.93 | 73.80 | 16.97 | 95.5 | 93.1 |
| DVR-08 | 4.7 | 79.91 | 0.61 | 79.30 | 3.97 | 1.84 | 73.50 | 16.98 | 95.0 | 92.7 |
| DVR-09 | 5.0 | 82.73 | 0.00 | 82.73 | 13.25 | 2.73 | 66.74 | 16.55 | 84.0 | 80.7 |
| DVR-11 | 5.0 | 83.65 | 0.00 | 83.65 | 3.39 | 2.77 | 77.49 | 16.73 | 96.0 | 92.6 |
| DVR-14 | 5.0 | 85.37 | 0.00 | 85.37 | 10.45 | 2.20 | 72.71 | 17.07 | 87.8 | 85.2 |
| DVR-16 | 4.7 | 71.66 | 0.00 | 71.66 | 2.94 | 1.26 | 67.46 | 15.35 | 95.9 | 94.1 |
| DVR-18 | 4.7 | 71.66 | 0.00 | 71.66 | 4.53 | 2.26 | 64.88 | 15.35 | 93.7 | 90.5 |
| DVR-20 | 4.7 | 81.55 | 0.00 | 81.55 | 3.67 | 1.66 | 76.22 | 17.46 | 95.5 | 93.5 |

## TABLE 5

Summary of nitrogen data for studies at 3.17 MPa.

| Subject | Study Days | TOTALS FOR STUDY PERIOD | | | | | | Daily Intake (GM N) | Daily Balance (GM N) |
|---|---|---|---|---|---|---|---|---|---|
| | | Provided (GM N) | Refused (GM N) | Consumed (GM N) | Stool (GM N) | Urine (GM N) | Balance (GM N) | | |
| DVR-01 | 7.0 | 125.6 | 17.9 | 107.7 | 23.0 | 107.1 | -22.4 | 15.4 | -3.2 |
| DVR-02 | 7.0 | 125.6 | 17.0 | 107.7 | 12.1 | 93.4 | 2.3 | 15.4 | 0.3 |
| DVR-03 | 7.0 | 143.1 | 23.6 | 119.5 | 10.6 | 99.8 | 9.2 | 17.1 | 1.3 |
| DVR-06 | 7.0 | 138.5 | 17.7 | 120.8 | 16.2 | 120.6 | -16.1 | 17.3 | -2.3 |
| DVR-09 | 7.0 | 143.1 | 31.9 | 111.2 | 13.3 | 84.1 | 13.9 | 15.9 | 2.0 |
| DVR-10 | 7.0 | 125.6 | 36.6 | 89.0 | 10.7 | 110.6 | -32.3 | 12.7 | -4.6 |
| DVR-11 | 7.0 | 143.1 | 18.8 | 124.4 | 12.2 | 136.1 | -23.9 | 17.8 | -3.4 |
| DVR-12 | 7.0 | 125.6 | 24.7 | 100.9 | 8.4 | 92.3 | 0.1 | 14.4 | 0.0 |
| DVR-13 | 7.0 | 138.5 | 9.6 | 128.9 | 11.8 | 37.6 | 79.4 | 18.4 | 11.3 |
| DVR-14 | 7.0 | 143.1 | 15.8 | 127.3 | 11.1 | 138.3 | -22.1 | 18.2 | -3.2 |
| DVR-15 | 7.0 | 138.5 | 18.7 | 119.8 | 10.0 | 116.8 | -7.0 | 17.1 | -1.0 |
| DVR-17 | 7.0 | 138.5 | 19.4 | 119.1 | 43.4 | 135.6 | -59.9 | 17.0 | -8.6 |
| DVR-19 | 7.0 | 138.5 | 24.4 | 114.1 | 13.7 | 103.7 | -3.3 | 16.3 | -0.5 |

**TABLE 6**

Summary of nitrogen data for studies at 0.56 MPa.

| Subject | Study Days | TOTALS FOR STUDY PERIOD Provided (GM N) | Refused (GM N) | Consumed (GM N) | Stool (GM N) | Urine (GM N) | Balance (GM N) | Daily Intake (GM N) | Daily Balance (GM N) |
|---|---|---|---|---|---|---|---|---|---|
| DVR-01 | 6.0 | 122.2 | 0.0 | 122.2 | 14.4 | 121.6 | -13.8 | 20.4 | -2.3 |
| DVR-04 | 6.0 | 122.2 | 0.3 | 121.9 | 12.5 | 145.7 | -36.4 | 20.3 | -6.1 |
| DVR-05 | 7.0 | 144.3 | 0.1 | 144.3 | 19.7 | 46.1 | 78.4 | 20.6 | 11.2 |
| DVR-09 | 7.0 | 144.3 | 11.2 | 133.1 | 17.3 | 45.3 | 70.5 | 19.0 | 10.1 |
| DVR-11 | 7.0 | 144.3 | 0.6 | 143.7 | 18.2 | 101.5 | 24.0 | 20.5 | 3.4 |
| DVR-14 | 7.0 | 144.3 | 13.9 | 130.4 | 17.8 | 42.2 | 70.5 | 18.6 | 10.1 |
| DVR-16 | 6.0 | 122.2 | 0.1 | 122.1 | 14.3 | 119.7 | -11.9 | 20.3 | -2.0 |

## TABLE 7

Summary of nitrogen data for studies at SURFACE.

| Subject | TOTALS FOR STUDY PERIOD | | | | | | | Daily Intake (GM N) | Daily Balance (GM N) |
|---|---|---|---|---|---|---|---|---|---|
| | Study Days | Provided (GM N) | Refused (GM N) | Consumed (GM N) | Stool (GM N) | Urine (GM N) | Balance (GM N) | | |
| DVR-01 | 4.7 | 97.3 | 0.0 | 97.3 | 7.5 | 38.5 | 51.3 | 20.8 | 11.0 |
| DVR-04 | 4.7 | 97.3 | 0.0 | 97.3 | 8.8 | 58.0 | 30.5 | 20.8 | 6.5 |
| DVR-05 | 5.0 | 103.4 | 0.2 | 103.1 | 12.1 | 95.7 | -4.7 | 20.6 | -0.9 |
| DVR-07 | 4.7 | 107.1 | 0.1 | 107.0 | 9.7 | 71.9 | 25.4 | 22.9 | 5.4 |
| DVR-08 | 4.7 | 107.1 | 0.1 | 107.0 | 10.6 | 60.6 | 35.8 | 22.9 | 7.7 |
| DVR-09 | 5.0 | 103.4 | 0.1 | 103.2 | 36.1 | 77.9 | -10.7 | 20.6 | -2.1 |
| DVR-11 | 5.0 | 103.4 | 0.2 | 103.1 | 8.7 | 70.7 | 23.7 | 20.6 | 4.7 |
| DVR-14 | 5.0 | 103.4 | 0.0 | 103.4 | 28.5 | 70.3 | 4.6 | 20.7 | 0.9 |
| DVR-16 | 4.7 | 97.3 | 0.0 | 97.3 | 7.9 | 40.1 | 49.4 | 20.8 | 10.6 |
| DVR-18 | 4.7 | 97.3 | 0.0 | 97.3 | 10.9 | 70.0 | 16.4 | 20.8 | 3.5 |
| DVR-20 | 4.7 | 107.1 | 0.0 | 107.1 | 10.8 | 61.7 | 34.6 | 22.9 | 7.4 |

## TABLE 8

Summary of body composition data at 3.17 MPa. Lean mass obtained by underwater weighing. Total body water obtained as deuterium space.

| | BEFORE DIVE | | DAY 2 AT DEPTH | | DAY 15 AT DEPTH | | END OF DIVE | | CHANGE AT DEPTH | | CHANGE FOR DIVE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight (KG) | Lean Mass (KG) | Weight (KG) | Total Water (KG) | Weight (KG) | Total Water (KG) | Weight (KG) | Lean Mass (KG) | Weight (KG) | Total Water (KG) | Weight (KG) | Lean Mass (KG) |
| DVR-01 | 81.20 | 65.78 | 80.74 | 50.68 | 76.20 | 49.43 | 76.48 | 61.84 | -4.54 | -1.24 | -4.72 | -3.94 |
| DVR-02 | 75.36 | 60.97 | 73.03 | 44.70 | 70.31 | 44.28 | 71.80 | 58.93 | -2.72 | -0.42 | -3.56 | -2.04 |
| DVR-03 | 64.86 | 58.16 | 64.86 | | 63.50 | | 64.34 | 57.25 | -1.36 | | -0.52 | -0.91 |
| DVR-06 | 77.90 | 66.14 | 78.02 | 53.47 | 78.47 | 45.72 | 77.30 | 63.79 | 0.45 | -7.75 | -0.60 | -2.36 |
| DVR-09 | 89.34 | 71.60 | 88.45 | 53.66 | 84.82 | 50.50 | 86.52 | 68.26 | -3.63 | -3.17 | -2.82 | -3.34 |
| DVR-10 | 79.02 | 66.74 | 77.11 | 49.25 | 74.39 | 52.66 | 75.86 | 65.92 | -2.72 | 3.40 | -3.16 | -0.82 |
| DVR-11 | 80.64 | 64.37 | 81.19 | 48.71 | 78.47 | 44.14 | 79.28 | 63.76 | -2.72 | -4.67 | -1.36 | -0.61 |
| DVR-12 | 61.36 | 54.62 | 61.24 | 37.88 | 58.06 | 40.95 | 60.04 | 53.06 | -3.18 | 3.07 | -1.32 | -1.57 |
| DVR-13 | 90.90 | 72.85 | 90.72 | | 90.72 | | 87.50 | 70.74 | 0.00 | | -3.40 | -2.10 |
| DVR-14 | 68.78 | 56.88 | 69.40 | 45.92 | 66.68 | 42.70 | 67.28 | 55.26 | -2.72 | -3.22 | -1.50 | -1.62 |
| DVR-15 | 90.22 | 76.11 | 90.27 | 61.40 | 89.81 | 59.82 | 86.40 | 74.77 | -0.45 | -1.58 | -3.82 | -1.34 |
| DVR-17 | 72.42 | 56.37 | 70.31 | 41.78 | 71.21 | 42.16 | 69.54 | 55.40 | 0.91 | 0.38 | -2.88 | -0.98 |
| DVR-19 | 70.68 | 57.93 | 69.85 | 44.40 | 67.59 | 41.66 | 66.40 | 54.78 | -2.27 | -2.73 | -4.28 | -3.15 |

**TABLE 9**

Summary of body composition data at 0.6 MPa.
Total body water obtained as deuterium space.

| | BEFORE DIVE | | AT END OF DIVE | | CHANGE DURING DIVE | |
|---|---|---|---|---|---|---|
| SUBJECT | WEIGHT (KG) | TOTAL WATER (KG) | WEIGHT (KG) | TOTAL WATER (KG) | WEIGHT (KG) | TOTAL WATER (KG) |
| DVR-01 | 81.98 | 46.37 | 82.55 | 46.11 | 0.57 | -0.25 |
| DVR-04 | 90.00 | 53.81 | 89.02 | 54.09 | -0.98 | 0.28 |
| DVR-05 | 86.09 | 49.33 | 86.64 | 47.60 | 0.55 | -1.73 |
| DVR-09 | 84.14 | 52.50 | 82.55 | 52.71 | -1.59 | 0.21 |
| DVR-11 | 77.16 | 47.75 | 78.93 | 46.58 | 1.77 | -1.17 |
| DVR-14 | 68.92 | 46.74 | 70.76 | 46.45 | 1.84 | -0.30 |
| DVR-16 | 82.10 | 45.87 | 82.33 | 47.15 | 0.23 | 1.28 |

**TABLE 10**

Summary of metabolic data obtained during saturation dives.

| | CONDITION (MPa) | SUBJECTS | MEAN | S D |
|---|---|---|---|---|
| ENERGY CONSUMED (MJ / DAY) | SURFACE | 11 | 16.28 | .82 |
| | 0.56 | 7 | 16.39 | .61 |
| | 3.17 | 13 | 11.99 | .92 |
| NITROGEN INTAKE (GM / DAY) | SURFACE | 11 | 21.3 | 1.0 |
| | 0.56 | 7 | 20.0 | 0.8 |
| | 3.17 | 13 | 16.4 | 1.6 |
| WEIGHT CHANGE (KG) | 0.56 | 7 | 0.34 | 1.28 |
| | TOTAL, ON BOTTOM 3.17 | 13 | -1.92 | 1.68 |
| | TOTAL, ALL DIVE 3.17 | 13 | -2.61 | 1.40 |
| CHANGE IN BODY COMPOSITION (KG) | TOTAL WATER 0.56 | 7 | -0.24 | 0.99 |
| | LEAN MASS ALL DIVE 3.17 | 13 | -1.90 | 1.05 |
| | TOTAL WATER ON BOTTOM 3.16 | 11 | -1.63 | 3.10 |
| NITROGEN BALANCE (GM / DAY) | SURFACE | 11 | 5.0 | 4.3 |
| | 0.56 | 7 | 3.5 | 7.1 |
| | 3.17 | 13 | -0.9 | 4.6 |
| DIGESTIBLE ENERGY (PERCENT) | SURFACE | 11 | 93.5 | 3.9 |
| | 0.56 | 7 | 94.1 | 0.4 |
| | 3.17 | 13 | 93.1 | 3.2 |
| METABOLIZABLE ENERGY (PERCENT) | SURFACE | 11 | 90.7 | 4.1 |
| | 0.56 | 7 | 91.7 | 1.9 |
| | 3.17 | 13 | 88.7 | 3.4 |

## FIGURE LEGEND

Figure 1. Divers' weight change during two-week period at 3.17 MPa.

# WEIGHT CHANGE VS. DAILY ENERGY INTAKE
## AT 3.17 MPa